Small Combatant Craft Science and Technology Interest Areas

APRIL 2013

Point of Contact
Robert A. Brizzolara, Ph.D.
Office of Naval Research
Sea Platforms and Weapons Division (Code 333)
875 N. Randolph St.
Arlington, VA 22203

PREAMBLE

This document describes Science and Technology (S&T) interest areas for Small Combatant Craft, manned and unmanned. The document is intended to communicate S&T priorities for Small Combatant Craft to industry, academia and government. There is no specific funding opportunity tied to the S&T Opportunities described in this document; interested parties are encouraged to speak directly with an ONR Program Officer.

INTRODUCTION

The Office of Naval Research (ONR) mission, defined in law, is to plan, foster and encourage scientific research in recognition of its paramount importance as related to the maintenance of future Naval power and the preservation of National Security[1], and to manage the Navy's basic and applied research and advanced development to foster transition from S&T to higher levels of research, development, test and evaluation[2]. The Naval S&T Vision[3] is to sponsor scientific research and technology to:

- Pursue revolutionary, game-changing capabilities for Naval forces of the future
- Mature and transition S&T advances to improve existing Naval capabilities
- Respond quickly to current Fleet and Force critical needs, and
- Maintain broad technology investments to hedge against uncertainty and to anticipate and counter potential technology surprise

Pursuant to these objectives, the Sea Platforms and Weapons Division of the Office of Naval Research (ONR-333) collaborated with the Carderock Division of the Naval Surface Warfare Center (NSWCCD) to identify Science and Technology (S&T) opportunities aimed at enhancing the operational capabilities of small naval combatant craft, manned and unmanned. This was accomplished via a series of meetings among representatives from ONR, NSWCCD, and stakeholders from relevant operational and acquisition commands within the Navy. The Small Combatant Craft S&T priorities and the process used to develop them are the subjects of this report. The technical scope of this document is Hull, Mechanical and Electrical (H, M & E) aspects of small combatant craft, including autonomous control of the craft, and launch, recovery and refueling. In addition, this document has an S&T scope:

6.1 - Basic Research

- Generates and exploits fundamental scientific discoveries and knowledge needed to envision, create, and develop new military capabilities
- By its very nature, Basic Research involves:
    - *Uncertainty: Basic Research explores the unknown.* It is common and prudent to examine multiple candidate paths before pursuing the most promising solution
    - *Persistence:* At the current level of understanding, many research efforts must be sustained over a period of years to achieve credible success

6.2 - Applied Research

- Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met
- Effort to fill capability gaps defined by the Department of Defense (DoD)
- Basic step to demonstrate initial military utility

6.3 - Advanced Technology Development

- Includes all efforts that have moved into the development and integration of hardware/software for field experimentation and tests
- Effort to fill Capability gaps defined by DoD
- Demonstrates military utility

This corresponds to Technology Readiness Levels (TRL) 1-6; see Figure 1.

S&T PRIORITIZATION PROCESS

The S&T opportunities support the overarching ONR vision for small combatant craft: "develop and implement S&T to enable scalable and cost-effective multi-mission manned/unmanned surface platforms that provide sea-based power projection through persistent anytime, anywhere access". A flow chart for the S&T prioritization process is depicted in Figure 2. The S&T priorities are grounded in customer needs. The process initiated with a series of meetings with the customers to identify these needs (red box in Figure 2, and box at top-center of that Figure). This document defines the S&T required to fill these customer needs. As part of the process, ONR 333 conducted two workshops. In the first, S&T challenges or gaps were identified that, if successfully addressed, could lead to significant cross-cutting improvements in the operational capabilities of small combatant craft. In the second workshop recommendations were developed for specific S&T approaches and technologies to fill the S&T gaps.

First Workshop

The first of the two S&T Workshops was held at NSWC-Carderock, Bethesda, MD in November 2010 (gold box in Figure 2). The objective of the first Workshop was identification of S&T challenges that, if successfully addressed, would lead to significant, cross-cutting improvements in the operational capabilities of small combatant craft, manned and unmanned. Attendees were drawn from government, industry and academia. The product of the First Workshop was an identification of the S&T challenges for small combatant craft. Subsequent to the Workshop, a team of ONR and Carderock experts consolidated this into a consolidated list of 11 S&T challenges (or gaps), listed in Figure 2. Additionally, following the First Workshop, a compilation was made by ONR of existing S&T projects relevant to each of the S&T gaps. Of course, the collection of existing S&T projects is dynamic, as new S&T projects are initiated and others end. Activities associated with the first Workshop concluded with a further refinement of customer needs via a series of meetings (light blue box in Figure 2).

Second Workshop

The Second Workshop was held in Arlington, VA in September 2011 (dark blue box in Figure 2). The objective was to identify S&T investment shortfalls in the area of Small Combatant Craft H, M & E and to develop recommendations for specific S&T approaches and technologies that could fill S&T gaps identified in the first Workshop. The Workshop was Government-only, since topics relating to future Navy investment decisions were being discussed. Five panels were identified, composed of ONR and NSWC-Carderock personnel. Each panel was assigned one or more of the S&T Gaps and was tasked with developing recommendations for specific S&T approaches and technologies that might solve technical challenges associated with small combatant craft H, M & E systems and result in significant improvement in small craft capability. The panels were charged with looking across industry, academia and government for the most compelling new S&T approaches. Each of the panels was asked to identify a total of 4-6 S&T approaches that addressed the S&T Gaps they were responsible for. The panels developed these recommendations prior to the Workshop. The panelists were asked to provide the following key information that would help ONR assess the proposed technology or approach:

- Objective of proposed work
- How is it done today/current practice?
- Proposed approach – what are the key technical ideas?
- What is new about the proposed approach and what evidence is there that it will be successful (modeling, calculation, experiment)?
- Risks
- Current Technology Readiness Level (TRL) (see Figure 1).
- If successful, what difference will it make? What is the benefit to the Warfighter?

Each panel was led by an ONR Program Officer and was allotted two hours to present their recommendations to the group. All workshop participants were encouraged to question or comment on each of the recommended approaches and technologies and to provide feedback. Feedback from the group was provided in two ways: (1) via written comment sheets that were submitted by each Workshop participant at the end of each panel's presentations, and (2) via an informal prioritization process provided by the Workshop participants at the end of the Workshop. There were a total of thirty-eight S&T approaches and technologies recommended by the Workshop panels. Subsequent to the Workshop, the approaches and technologies specific to Small Combatant Craft and that are publicly releasable were distilled into the 4 areas discussed in the remainder of this report.

SMALL COMBATANT CRAFT S&T INTEREST AREAS

The following describes the S&T Interest Areas and particular S&T Opportunities within those Interest Areas. There is no specific funding opportunity tied to the S&T Opportunities described in this document

S&T Interest Area #1: Physics-Based Structural Design Methods and Structural Load Determination to Enable a Reduced Structural Weight Fraction Planing Hull

S&T Opportunities:

(1) Performance metrics and assessment criteria for predicting slamming pressures, impact loads and structural response of planing craft and boats. See Figure 3.

- Efficient, accurate computational methods to predict slamming pressures, and resulting structural loads and response. Verification and validation of computational methods is of key importance.
- Assessment of the importance of hydroelastic response.

(2) Reliability-based design approaches for planing craft, quantify the slamming process for planing craft and develop statistical methods for the prediction of design loads

How is it Done Today/Limitations of Current Approach: Current design methods utilized by the Navy for small combatant craft employ empirical procedures and can introduce excessive conservatism into the design and sub-optimization of structural weight. The current structural design process provides no capability for evaluating use of alternative materials and hydroelastic behavior.

Challenges: The complexity of the interaction between platform and water makes accurate computational modeling technically challenging. State-of-the-art computational tools that account for all relevant physics, and a robust verification and validation will be necessary. One of the principal risks is acceptance of new design methodology by standards organizations and Navy; therefore, early and frequent communication with these organizations and a robust verification and validation approach will be of key importance.

Benefit: Application of probabilistic and reliability-based approaches will allow the structural designer to rigorously account for uncertainties associated with material properties and structural loads. Potential to reduce overall weight will help maximize platform attributes such as increased endurance, payload and/or fuel capacity. Ability to predict material and structure behavior during slamming loading events will provide the means to optimize local structural design.

S&T Interest Area # 2: Understanding the physics and hydrodynamics of advanced hullforms: computational modeling with robust verification and validation

S&T Opportunities:

(1) Understanding and optimization of the characteristics of advanced hullforms that address the highest-priority platform attributes (ride quality, efficiency and speed). Example hullforms include, but are not are limited to, stepped hulls,

suspended sponson, suspension hulls, multihulls, tailored stiffness or compliant structures, and various lifting bodies and appendages, etc.

(2) Adapt and assess existing computational fluid dynamics (CFD) codes that will enable Navy to perform an initial evaluation of novel hullforms prior to building, and obtain evidence of performance enhancements relative to existing craft. See Figure 4. A key aspect will be a robust verification and validation of the CFD tools.

How is it done today/Limitations of current practice: The Navy currently uses planing hulls for most small combatant craft applications. The Navy evaluates hullforms by performing detailed on-water assessments of full-scale craft, which is expensive.

Challenges:

(1) Complexity in modeling fine details of advanced hullforms will challenge the CFD codes

(2) Verification and validation of CFD codes

Benefit:

Characterization, understanding and optimization of advanced hullforms using computational tools will provide an initial evaluation tool that will inform subsequent decisions by the Navy regarding building and testing partial or full-scale prototypes. This will focus resources for testing physical models on the highest benefit concepts and result in substantial cost savings. Successful use of small craft simulation tools capable of modeling the motions, hull pressures and fine details would impact all aspects of small boat design, i.e., increased performance, and reduced cost. This will allow for more concept design evaluation at a lower cost, as well as the ability to design better-performing craft.

S&T Interest Area #3: USV Autonomous Maneuvering and Navigation; Autonomous Perception and Decision Making

S&T Opportunities: Develop reliable, fault-tolerant autonomy for long, complex missions in unpredictable or harsh environments, including own-ship speed, sea state, nighttime operations, fog, and marine layer. See Figure 5. The autonomy must be designed for the highly dynamic, unstructured environment that USVs experience.

(1) Efficient and effective algorithms and approaches for handling multiple competing objectives

(2) Intent determination, activity recognition and motion prediction of maritime vessels

(3) Improved situational awareness and accuracy of world model in degraded conditions such as high sea state, poor visibility, etc

(4) Approaches for adaptation of deliberative planning algorithms to real time operations

(5) Reflective autonomy/learning in the maritime environment

(6) Cooperative decision-making amongst groups of USVs, and USVs and other UxV types

(7) Accurate and fast fusion of sensor information including decentralized data fusion across several USVs, and USVs and other UxV types

(8) Performance metrics for autonomous control systems

How is it done today/Limitations of current practice: Current unmanned surface vehicles (USVs) use waypoint navigation, run scripts, and/or employ path planning algorithms. This requires substantial human operator cognitive workload and high bandwidth for streaming video for human's situational awareness.

Challenges:

(1) Degraded perception in challenging environments (visibility, sea state) results in inaccurate world model

(2) Degraded decision-making using uncertain and intermittent world-model information

(3) Inability of USV control system to recognize activities of other maritime craft and learn situations results in USV taking inappropriate actions

(4) Quantitative performance metrics for autonomous systems not yet developed. "Success" not yet well-defined.

Benefits: Increasing the level of autonomy in USV maneuvering and navigation will enable decreased human operator workload and decreased bandwidth for USV control. It will also enable beyond line-of-sight missions for USVs and USV operations in communications-denied environments. Finally, it may enable new design space for small craft, unconstrained by need to accommodate humans.

S&T Interest Area #4: S&T Supporting Launch, Recovery and Refueling

S&T Opportunities:

(1) Understanding and management of the relative motions between 2 bodies (for example, USV and host vessel, USV and UUV/UAV/USV, USV and sponson), and approaches for mitigation of relative motion, in high sea states. This may be USV to host vessel, USV to towed sponson/drogue, or UUV/UAV/USV to USV and includes automated launch, recovery and refueling systems. Effective use of computational fluid dynamics with robust verification and validation.

(2) Algorithms and approaches for short-term forecasting (2 ~ 5 sec.) of small-boat motions. See Figure 6.

How is it done today/Limitations of current practice:

(1) Launch and recovery of USVs is a human-intensive operation that involves substantial safety hazards

(2) USVs are retrieved onto host ship for refueling which is time-consuming and manpower-intensive

(3) UUVs are deployed/retrieved from manned boats, which may result in humans being placed in hazardous areas

(4) USV control systems have no capability to anticipate wave-induced platform motion, as a human operator does

Challenges

The fundamental technical challenge is the same for all of these activities: managing the sea surface-induced relative motions between the two platforms in high sea states to make or release a connection between the two platforms. Boat motion is nonlinear and therefore difficult to predict.

Benefits

This area will enable launch and recovery of a USV from a host vessel in higher sea states than currently possible, underway refueling of a USV from another vessel, and launch and recovery of UUVs, UAVs or USVs from a surface vessel or boat in higher sea states. It will also provide longer time on station for USV via underway refueling and longer time on station for small UAVs and UUVs.

REFERENCES

1. Public Law 588 of 1946.
2. Defense Authorization Act of 2001.
3. Naval S&T Strategic Plan, Office of Naval Research, 1 SEP 2011.
4. International Regulations for Preventing Collisions at Sea, International Maritime Organization, 1972.

LIST OF ACRONYMS

CFD: computational fluid dynamics

COLREGS: collision regulations

H, M & E: hull, mechanical and electrical

NSWCCD: Naval Surface Warfare Center, Carderock Division

ONR: Office of Naval Research

S&T: science and technology

TRL: technology readiness level

USV: unmanned surface vehicle

UxV: refers to a USV, unmanned aerial vehicle (UAV) or unmanned underwater vehicle (UUV)

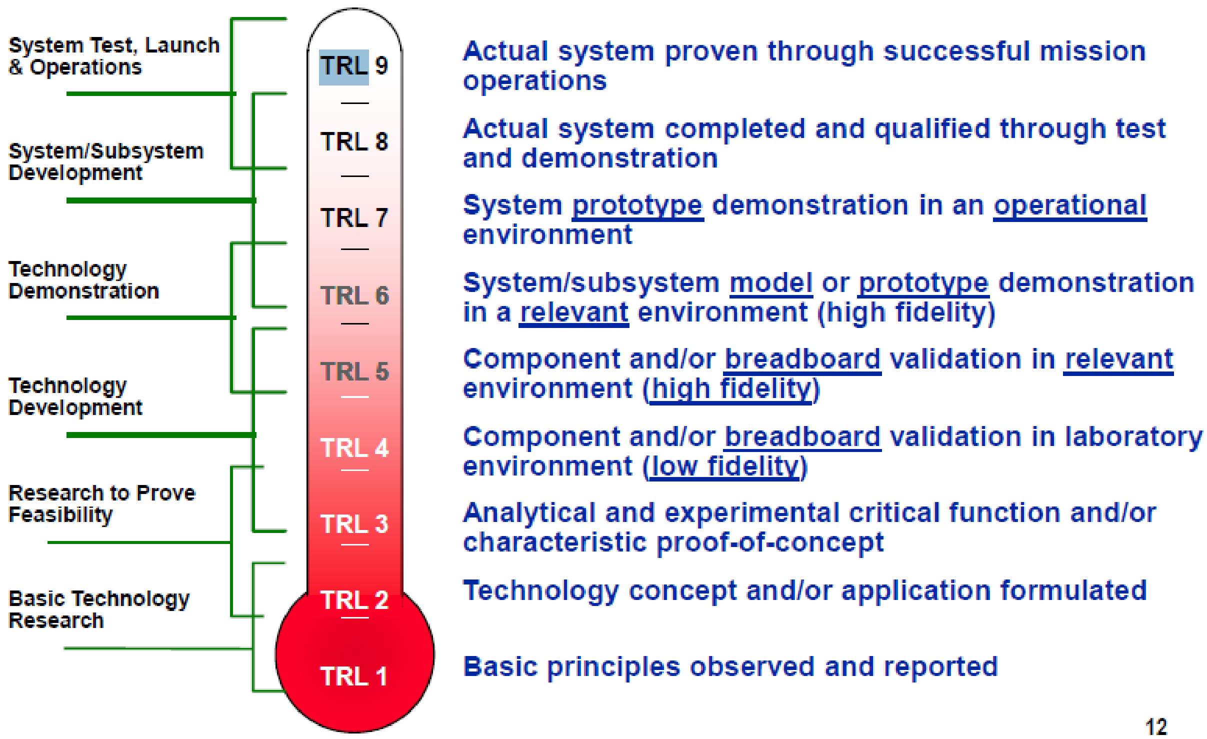

Figure 1. Technology Readiness Levels (TRL).

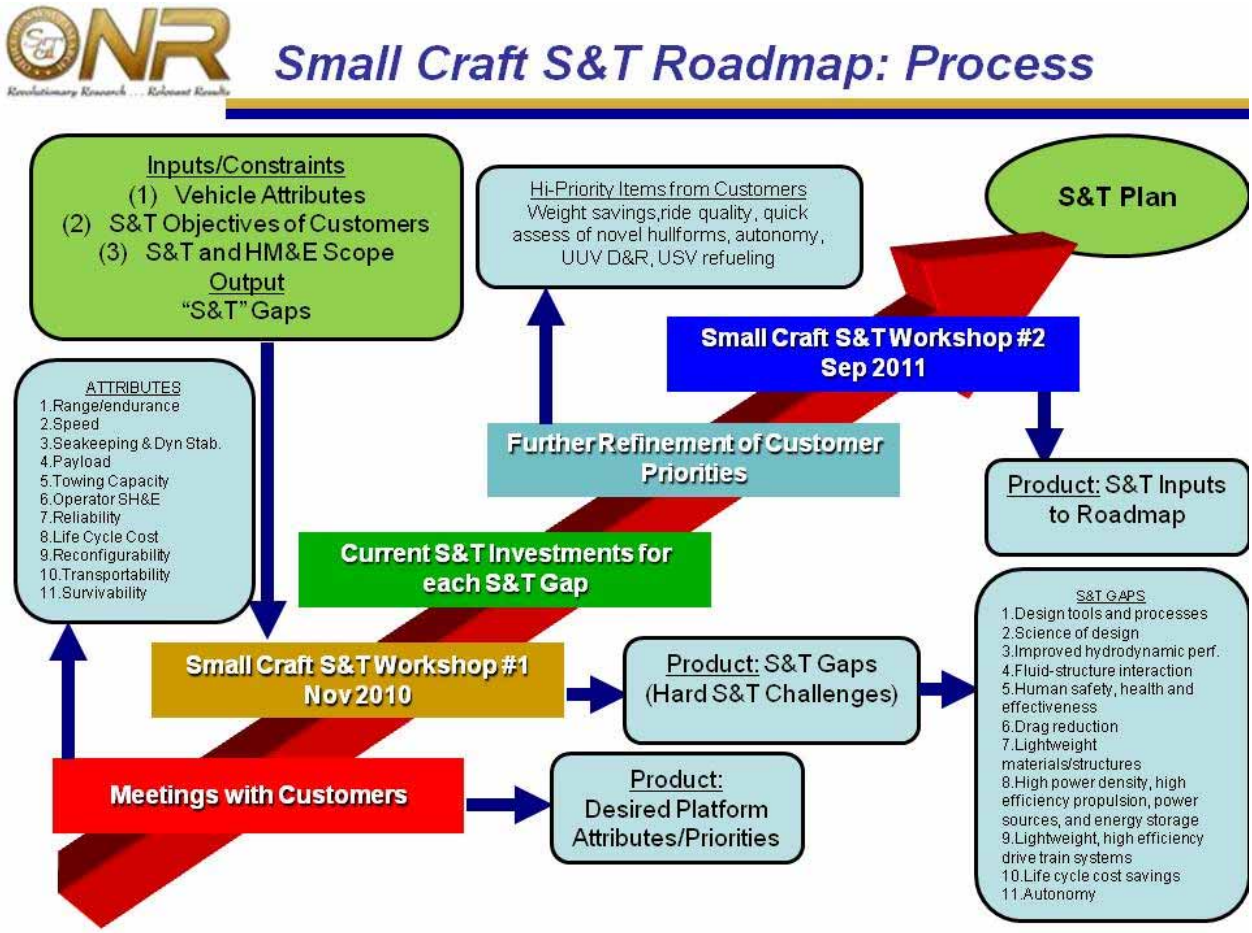

Figure 2. Small Combatant Craft S&T Roadmap: Process and Products.

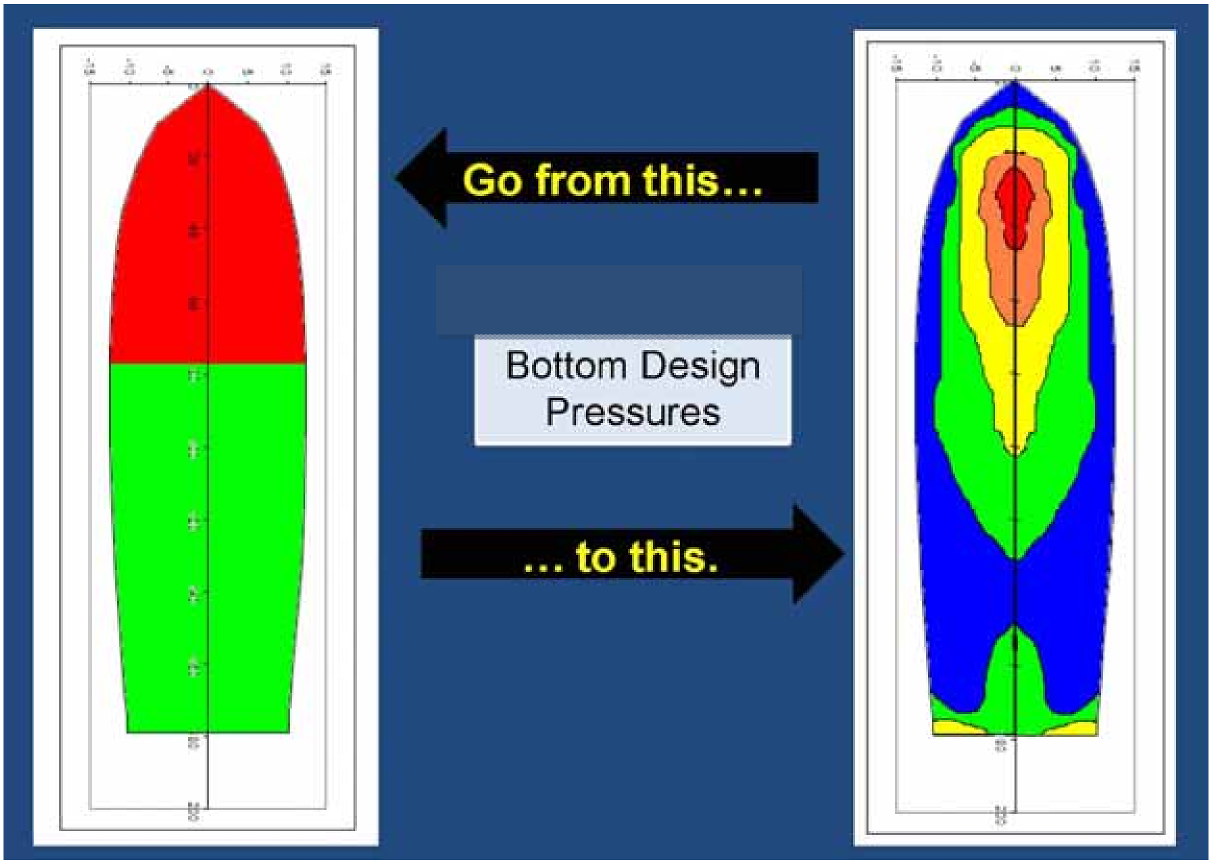

Figure 3. Notional depiction of improved computational hull pressure determination, for structural weight optimization (S&T Opportunity #1).

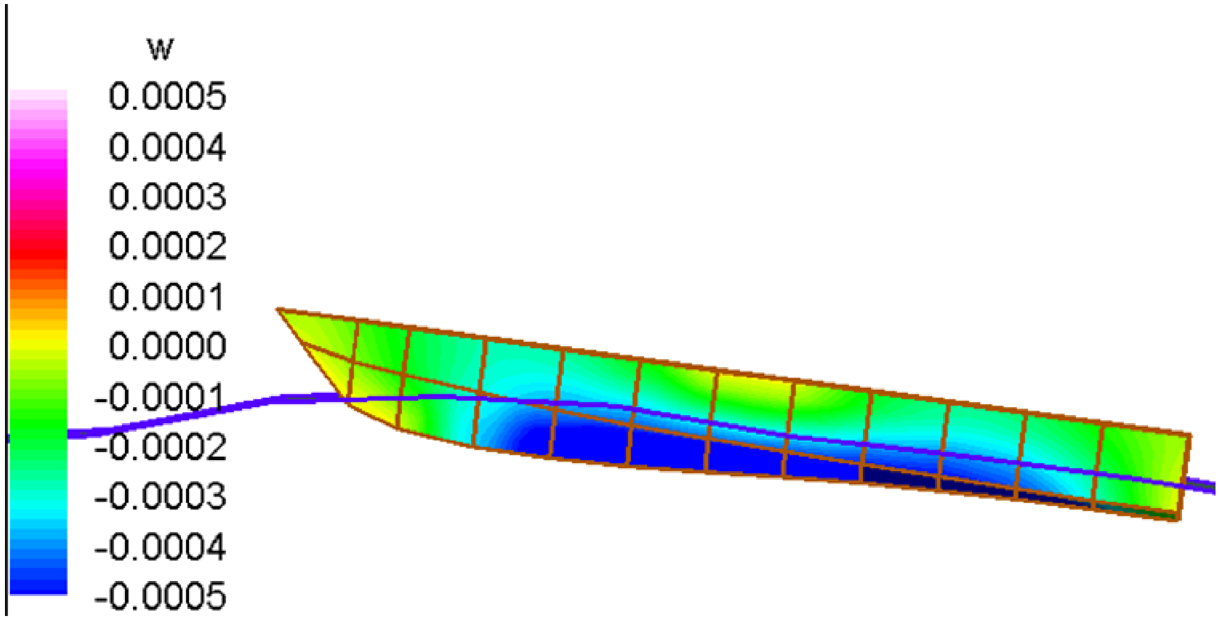

Figure 4. Computational fluid dynamic simulation of small boat motion in waves (S&T Opportunity #2).

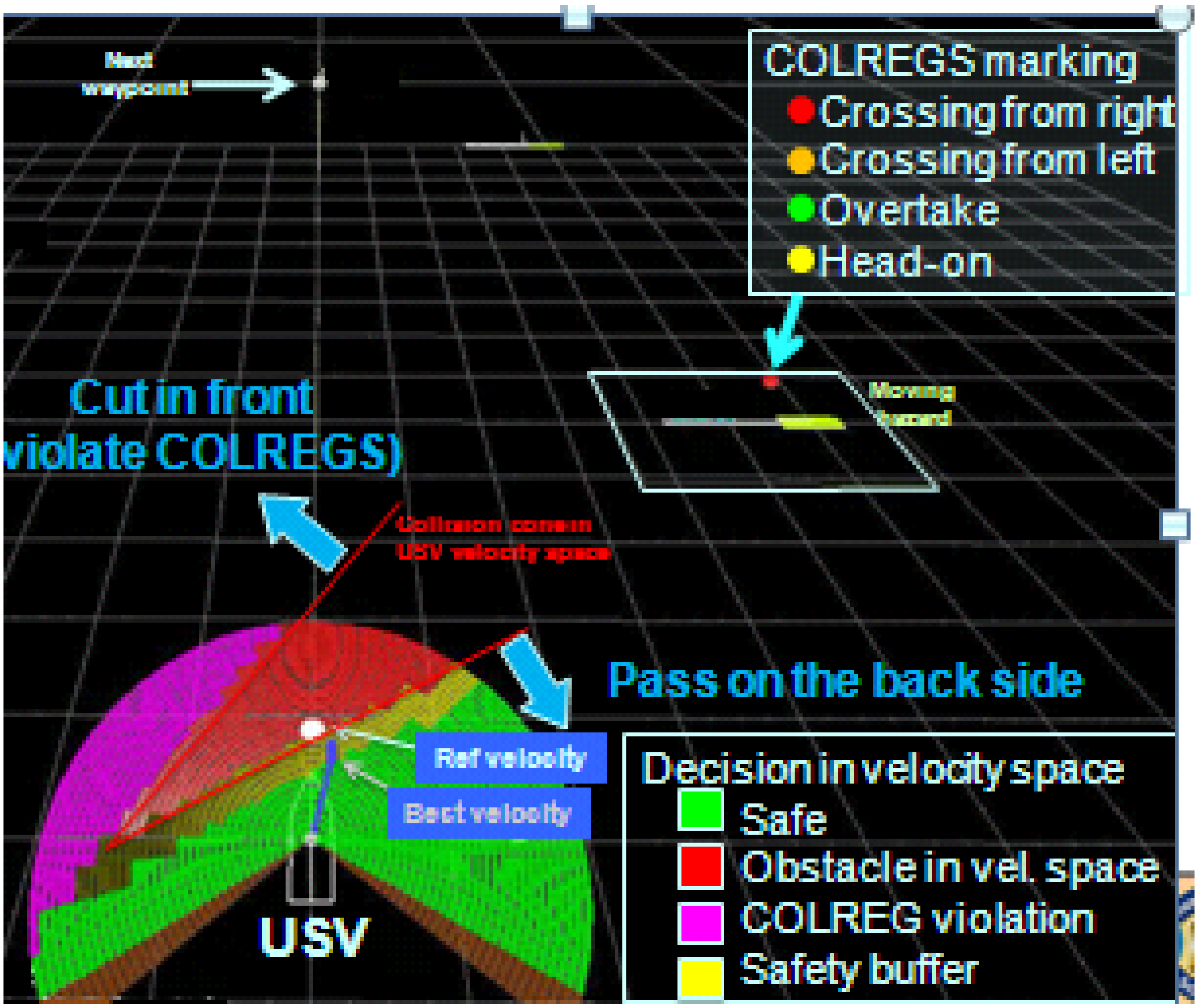

Figure 5. Depiction of behavior-based autonomous control system's course/speed decision-making for USV that is traveling to a waypoint (top of image), avoiding other surface traffic (yellow rectangle) and complying with appropriate collision regulation. The color plot centered on the USV is in velocity space: green indicates velocity vectors that are safe, red indicates velocity vectors that may result in a collision, and purple indicates velocity vectors that will result in a COLREG[4] violation (S&T Opportunity #3).

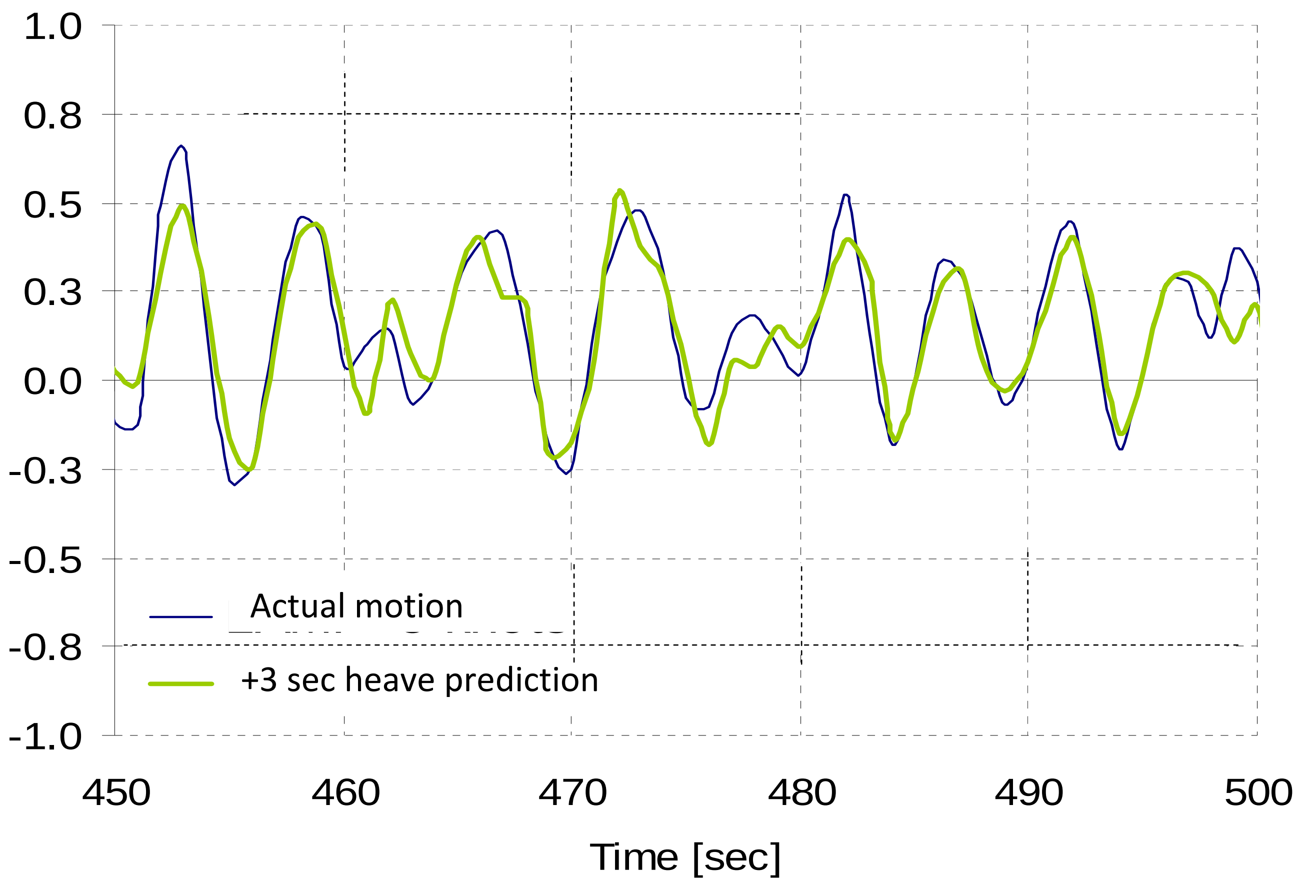

Figure 6. Example of a short-term heave motion forecast of a small boat in waves (S&T Opportunity #4).